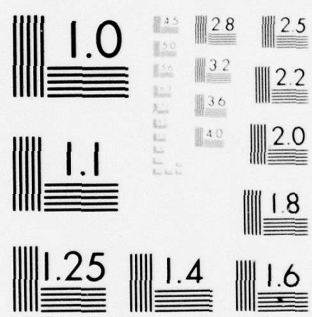
AD-A038 601 NAVAL WEAPONS CENTER CHINA LAKE CALIF F/G 1/2
AIRCRAFT FIRE SIMULATOR TESTING OF CANDIDATE FIRE BARRIER SYSTE--ETC(U)
NOV 76 H H HOFFMAN, J S FONTENOT
UNCLASSIFIED NWC-TP-5915 NL

1 OF 1
ADA038601

END
DATE
FILMED
5 - 77


1.0
4.5
5.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

NWC TP 5915

Aircraft Fire Simulator Testing of Candidate Fire Barrier Systems

by
Herman H. Hoffman
and
John S. Fontenot
Systems Development Department

NOVEMBER 1976

Naval Weapons Center
CHINA LAKE, CALIFORNIA 93555

Naval Weapons Center

AN ACTIVITY OF THE NAVAL MATERIAL COMMAND

R. G. Freeman, III, RAdm., USN . . . . Commander
G. L. Hollingsworth . . . . Technical Director

FOREWORD

This report presents results of aircraft fire barrier materials tests conducted in conjunction with an F-14A Aircraft Fire Protection Modification Testing Program in accordance with AirTask A510-5102/008-2/6241-000-436. Testing and evaluation of candidate fire barrier materials is presented. Recommendations relating to investigation of fire barrier materials are given.

The work reported was conducted between February and September 1976 by the Systems Survivability Branch, Naval Weapons Center, China Lake, Calif. Additional technical support for materials selection and test analysis was obtained from NASA-Ames Research Center, Grumman Aerospace Corporation, and AVCO Systems Division, Inc.

This report has been reviewed for technical accuracy by G. E. Moncsko and H. W. Drake.

Released by
M. M. ROGERS, *Head*
Systems Development Department
12 November 1976

Under authority of
G. L. HOLLINGSWORTH
Technical Director

NWC Technical Publication 5915

Published by . . . . Technical Information Department
Manuscript 2362/MS B0427
Collation . . . . Cover, 21 leaves
First printing . . . . 110 unnumbered copies

1 McClellan Air Force Base (ALC/MMSRBC, B. Nichols)
1 Norton Air Force Base (General Dynamics Representative, D. Guynne)
12 Defense Documentation Center
1 Federal Aviation Administration, Department of Transportation, Atlantic City (ARD/520, T. Horeff)
1 Federal Aviation Administration, National Aviation Facilities Experimental Center, Atlantic City (ANA/420, R. Russell)
4 Ames Research Center (NASA), Moffett Field
  Army Air Mobility Research and Development Laboratories
    SAVDL-AS, F. Immen (1)
  Chemical Research Projects Office
    R. Fish (1)
    Dr. J. Parker (1)
    S. Riccitiello (1)
1 Lyndon B. Johnson Space Center (NASA), Houston (ES-54, Dr. F. Dawn)
1 AVCO Corporation, Research and Systems Group, Systems Division, Lowell, MA (D. Patterson)
1 Bell Helicopter Corporation, Ft. Worth, TX (Survivability Group, J. Joggers)
1 Convair Division of General Dynamics, San Diego, CA (V/STOL Fighter-Attack Aircraft Group)
1 Fairchild Hiller Corporation, Famingdale, NY (A-10 S/U, J. Arrighi)
1 Falcon Research and Development Corporation, Denver, CO (L. Mahood)
1 General Dynamics Corporation/Fort Worth, Fort Worth, TX (MZ-2651, Dr. F. Tiberi)
2 Grumman Aerospace Corporation, Bethpage, NY
  J. P. Archey, Dept 662 (1)
  L. Loviseck, F-14 (1)
1 Hughes Aircraft Company, Culver City, CA (A. Edwards)
2 McDonnell Douglas Corporation, St. Louis, MO
  J. Poussen (1)
  E. Wiggins (1)
2 Northrop Corporation, Hawthorne, CA
  Code 3882/31, R. Kissling (1)
  Dept 3895/84, R. McCaffrey (1)
1 Rockwell International, Columbus, OH (R. Strohl)
1 Rockwell International, Los Angeles, CA (B-1 Division, B. Hatton)
1 Sikorsky Aircraft Division, Stratford, CT (J. Foulk)
1 The Boeing Company, Seattle, WA (R. Blaisdell)
1 Vought, Incorporated, Systems Division, Dallas, TX (Unit 2-55152, D. Reedy)

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

14

1. REPORT NUMBER: NWC-TP-5915

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

6

4. TITLE (and Subtitle): Aircraft Fire Simulator Testing of Candidate Fire Barrier Systems,

9

5. TYPE OF REPORT & PERIOD COVERED: Test and evaluation + Rept. February-Sep[redacted]976,

6. PERFORMING ORG. REPORT NUMBER

10

7. AUTHOR(s): Herman H. Hoffman, John S. Fontenot

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS: Naval Weapons Center, China Lake, Calif. 93555

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: AirTask A510-5102/008-2/6241-000-436

11. CONTROLLING OFFICE NAME AND ADDRESS: Naval Weapons Center, China Lake, Calif. 93555

11

12. REPORT DATE: Nov[redacted]76

13. NUMBER OF PAGES: 40

14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)

12 41p.

15. SECURITY CLASS. (of this report): UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

ACCESSION for
NTIS White Section ☑
DDC Buff Section ☐
UNANNOUNCED ☐

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

See back of form.

A

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

See back of form.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

S/N 0102-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

403019

1B

19. Aircraft Survivability
Aircraft Vulnerability
Aircraft Fires
Burn Tests
Fire Barrier
Intumescent Paints
Fire Resistant Materials
Fuel System Survivability
Organic Foams
Polyurethane Foam
Fire Protection

20. (U) *Aircraft Fire Simulator Testing of Candidate Fire Barrier Systems*, by Herman H. Hoffman and John S. Fontenot. China Lake, Calif., Naval Weapons Center, November 1976. 40 pp. (NWC TP 5915, publication UNCLASSIFIED.)

(U) The results of a study to evaluate candidate aircraft fire barrier materials to in-flight fires are presented. Four organic materials, two inorganic materials, and three metallics combined with insulators were tested in an in-flight fire simulator. Eight intumescent coatings were evaluated to determine their ability to close barrier gaps in the event of a fire.

CONTENTS

Introduction 3

Objective 5

Acceptance Criteria 6

Test Description 7
- Requirements 7
- Test Simulator Design 7
- Instrumentation 8
- Materials Tested 11
- Test Specimen Preparation 13
- Test Procedure 14

Test Results 15

Test Observations 22
- Polyurethane Foams 22
- Intumescent Paints 23
- Inorganic Materials 24
- Barrier Penetrations 24

Recommendations 25

Appendix A. Lightweight Fire Barrier Materials Development for Aircraft 27

INTRODUCTION

Candidate fire barrier systems were tested at the Naval Weapons Center (NWC), China Lake, Calif. to evaluate barrier system capabilities for use in aircraft. The test program was conducted as part of an F-14A Aircraft Fire Protection Modifications Testing Program performed under NAVAIR cognizance. However, due to the paucity of information relative to aircraft fire barrier materials and systems, data was obtained as a result of the test program that is applicable to all types of aircraft.

In-flight aircraft fires, whether the result of direct hostile action or the result of operational failures, are a major cause of military aircraft losses. Efforts to date to reduce this hazard have concentrated on fuel system containment. Where fuel containment and ignition prevention fails, fire propagation through an aircraft will often fail a flight critical component, such as flight controls, in an unacceptably short time period. The effort herein described has been directed toward developing barriers that will compartmentalize the aircraft interior, thus protecting critical components until the fire burns out or is actively extinguished.

An aircraft fire barrier test simulator was designed and fabricated at NWC to be used as a realistic screening apparatus for candidate fire barrier systems. The subsequent tests were directed toward obtaining thermal data and determining the fire-retention capabilities of a variety of foam-type materials in representative system concepts.

Requirements for retrofit installation capability and for barrier penetrations by necessary aircraft equipment were two major considerations in the test and evaluation of system concepts. Initial emphasis was directed toward barrier materials installation in existing aircraft using a building-block approach to installation. Therefore, the acquisition of data concerning the effect of joint design and gap closure under simulated aircraft fire conditions was pertinent to barrier systems evaluation. The use of intumescent paints as a closure medium for barrier gaps was tested. (Intumescent paints swell upon exposure to heat and flame thereby providing a gap-closure capability.) Problems associated with the building-block approach such as complicated shapes, difficult installation and maintenance, fastenings, and availability of materials led to later emphasis being directed toward metallic barriers combined with off-the-shelf insulators and sealants.

A portion of a proposed F-14 fire barrier installation is shown in Figure 1. The number and variety of equipment that penetrates the barrier is representative of problems encountered in installation of fire barrier materials.

The problem of barrier penetrations was also investigated. Two types of penetrations representative of those encountered in an aircraft were used. These consisted of (1) an electrical wire bundle, and (2) a thin-walled aluminum tube typical of a fuel vent line.

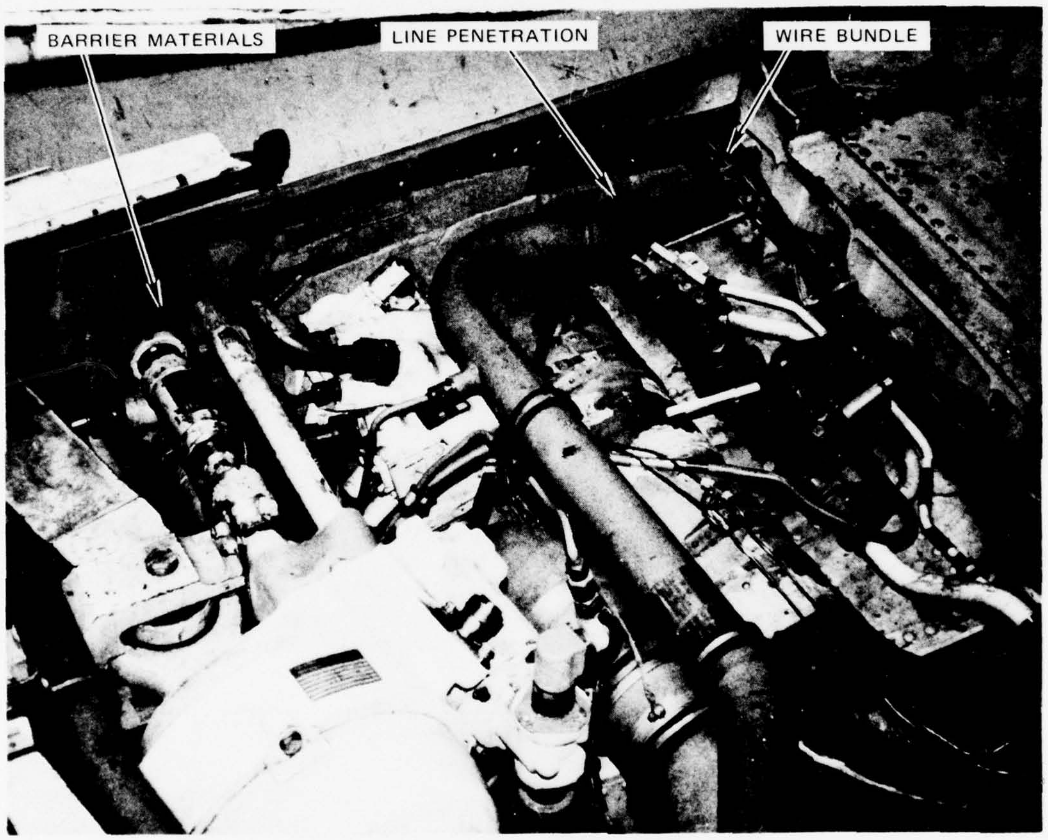


FIGURE 1. Typical Penetrations in a Fire Barrier Installation.

OBJECTIVE

The primary objective of this effort was to test candidate fire barrier systems and to document their response to the predicted thermal environment. Additionally, a lightweight barrier material was to be developed and evaluated to serve as an example system. (This effort is described in Appendix A.) Secondary objectives were identified as follows:

1. To identify the particular problem areas of aircraft structure and equipment penetration through barriers, clearance requirements, and flight induced loads while in a fire environment.

2. To develop criteria for an aircraft fire barrier specification containing realistic and attainable acceptance criteria.

ACCEPTANCE CRITERIA

In general, the basic acceptance criterion demands that the barrier system neither burn through nor let the temperature of the air space measured 15 cm (6 in.) normal to the barrier unexposed face exceed 205°C (400°F) for 10 min when tested in a fire barrier test simulator.

Consideration was given to test parameters applicable to preparation of a specification covering lightweight fire barrier systems. It was deemed important that specimen size, weight, joint configuration, and intumescent coatings of the specimens be held to close tolerances to avoid inconsistencies in test results. Uniform block size held to close tolerances, weight measured to tenths of a milligram, the absence of mechanical flaws and surface voids, and complete and uniform intumescent coating were all seen as important considerations. In addition, the development of environmental test requirements covering items such as shock, vibration, temperature, humidity, etc., would be required. A specification prepared on this basis could be applicable to both military and civilian aircraft.

TEST DESCRIPTION

REQUIREMENTS

The fire barrier simulation test requirements were based upon the need to generate a temperature, pressure, airflow, and heat flux environment duplicating predicted fire conditions in an in-flight environment for a period of up to 10 min without burnthrough and without allowing temperatures, as measured 15 cm (6 in.) normal to the barrier unexposed face, to exceed 205°C (400°F).

The conditions established for evaluation of candidate barrier systems were as follows:

1. A heat rate of approximately 11.35 $W/cm^2/sec$ (10 BTU/ft^2-sec) uniformly across the test specimen face.

2. An airflow velocity of approximately 5 m/sec (10 knots) across the test specimen face.

3. A nominally fuel-rich fire typical of that postulated to exist in a typical aircraft accidental on-board fire.

TEST SIMULATOR DESIGN

Design criteria were based upon the requirement to reproduce the temperature, pressure, airflow, and heat flux environment predicted for an in-flight aircraft with an internal fire. Specimen visibility and accessibility were also required to facilitate testing operations and observations.

The test simulator consists of a tunnel through which a controlled airstream is directed over a fire source. The upstream portion of the tunnel consists of an axial-flow fan shroud to direct and shape the airstream, a fuel pan, and a flame diffuser. The downstream section of the tunnel is angled at 30 deg to the forward section to cause impingement of the air-driven flame across the test specimen. A buffer plate upstream of the fuel pan acts as a flame holder, diffusing and shaping a uniform flame across the specimen.

A 50-cm (≈20 in.)-diameter axial flow fan powered by a universal motor with speed control is used to provide the tunnel airflow. The fan provides an airflow velocity of approximately 5 m/sec (10 knots) across the specimen face. A pressure differential of up to 35 gm/cm^2

(0.5 psi) can be obtained (when necessary) by mounting a cowled exhaust fan over the back (open) side of the test specimen.

The axial flow fan (household type) was selected to provide tunnel airflow because of its constant velocity characteristic. With this type fan, once the desired airflow velocity is set, the velocity remains fairly constant even if downstream flow area is reduced. Fans such as turbine or squirrel cage types will attempt to hold a given mass flow by increasing velocity, a feature not desired in this test fixture. An assembly drawing of the test simulator is presented in Figure 2.

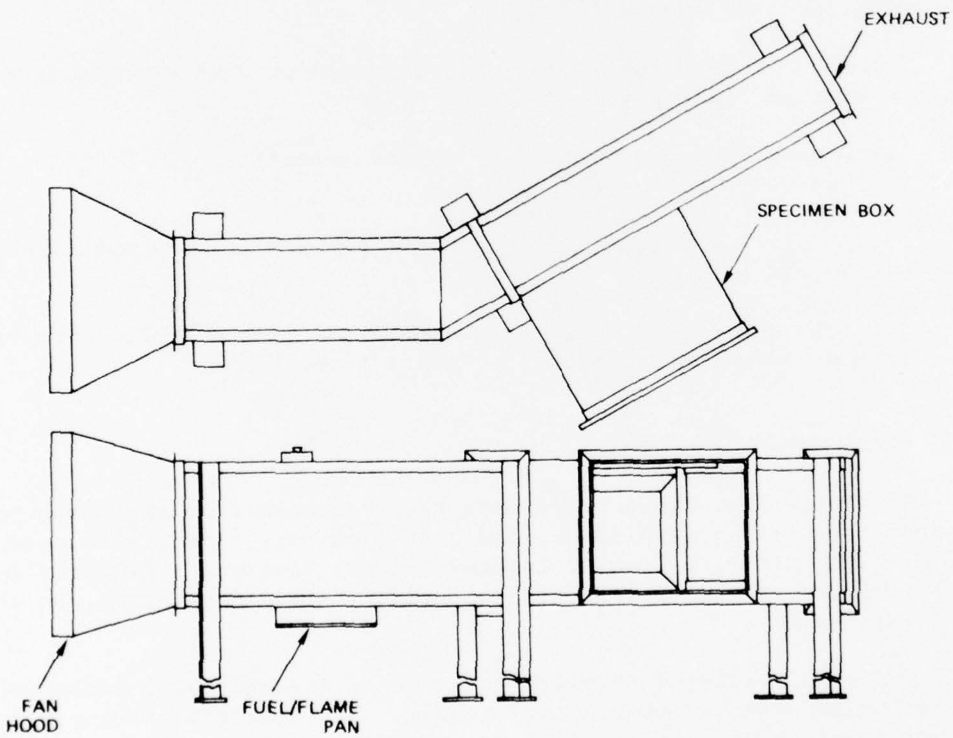


FIGURE 2. Aircraft Fire Test Simulator, Plan View.

INSTRUMENTATION

Instrumentation used for the fire barrier tests included a heat rate sensor, Type K chromel alumel (C-Al) thermocouples, a two-channel strip chart recorder, and a photographic camera. Data recording was accomplished using the instrumentation assembled as shown in Figure 3.

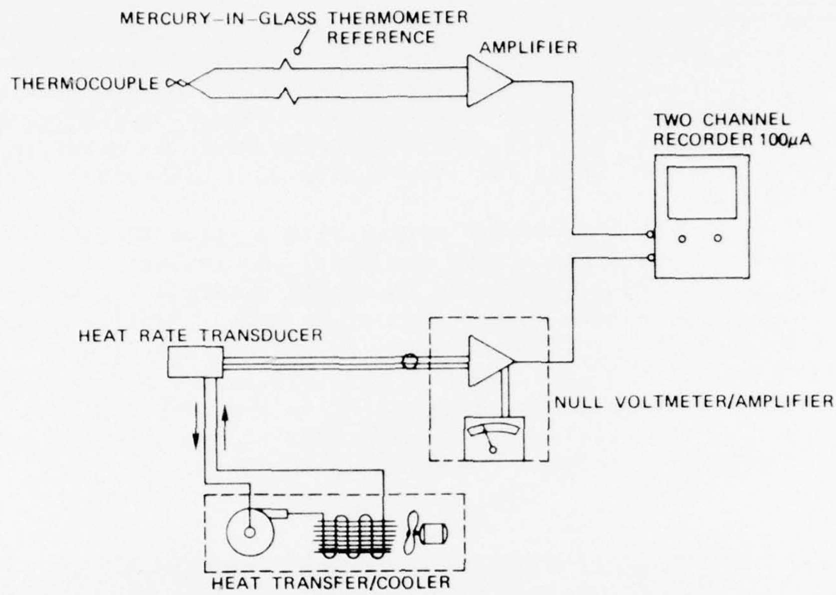


FIGURE 3. Aircraft Fire Test Simulator Instrumentation, Block Diagram.

Basic instrumentation consisted of a total heat calorimeter (asymptotic type) mounted upstream of the specimen and thermocouples mounted on the unexposed (backface) side of the specimen. Specimen thermocouples were mounted to a 2-cm(0.785-inch)-diameter aluminum disc of 0.16 cm (0.062 inch) thickness. For general specimen backface temperature measurements the thermocouple assemblies were bonded to the specimen backface with high-temperature adhesive. Clearance gap thermal data were obtained with bare thermocouples placed directly in the gaps.

During preliminary tests, the heat rate sensor was mounted in the test sample just protruding past the face. It was quickly found that outgassing of the foam volatiles and migration of the intumescent paint as it began to react would block the sensitive area of the sensor. Upstream relocation of the sensor remedied this problem without introducing significant measurement error.

Temperature measurement was accomplished by an unreferenced C-Al thermocouple mounted at the first upstream gap or joint between block samples. This position was felt to be the predominantly weaker point since outgassing would tend to provide a cool gas buffer between the flame and the foam block downstream. Also, this position allowed a measure of the time it took the gap to seal. To accomplish this on tests where a pressure differential was not applied to the test specimen, the exit of the test fixture was blocked at start of the test.

The fan blew fire through the gap between specimen blocks, which was subsequently sealed by the foam of the reacting intumescent paint. Upon sealing of the specimen gaps, the tunnel exit blockage was removed to allow free flow of fire across the specimen face. During later tests a pressure differential was accomplished by lowering the pressure on the unexposed specimen face using the intake side of a high-pressure blower.

A still camera (4 x 5 graphic camera with a Polaroid back) was used to record visual events during the test. An initial picture was taken of the mounted specimen sample to record assembly procedure and specimen block data; Figure 4 is a typical example. Additional photos were taken when events of interest occurred such as swelling of intumescent paint out of the gaps, general char across the specimen sample, and when fire broke through the sample. After the test a picture was taken of the fire-exposed face of the specimen to show erosion and/or failures. A typical test setup is shown in Figure 5.

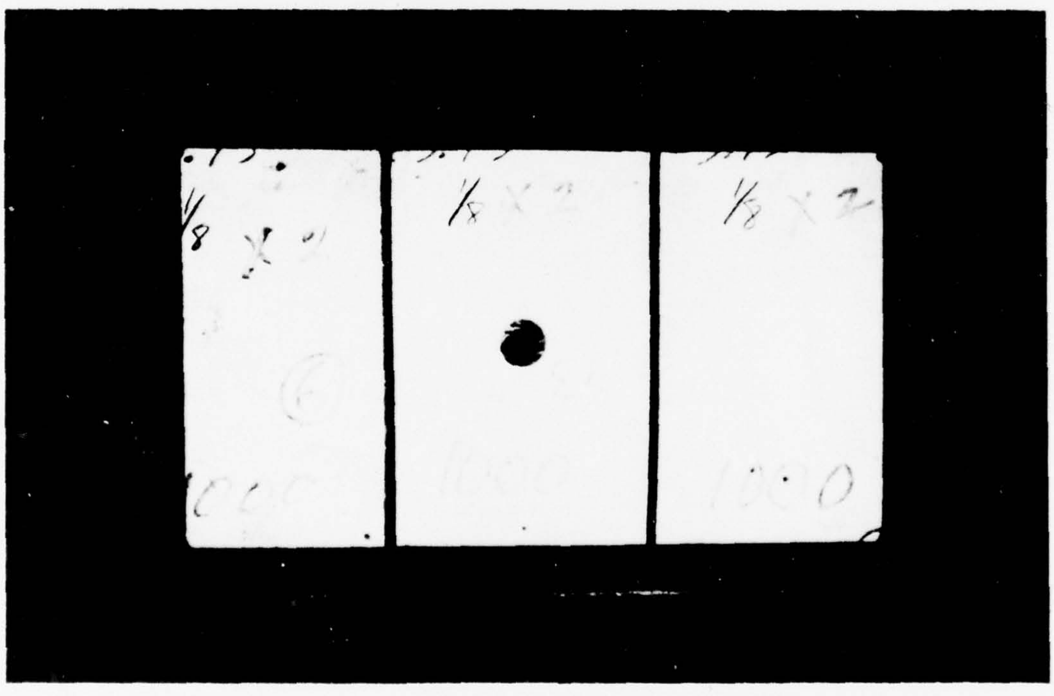


FIGURE 4. Candidate Barrier Specimen Prepared for Aircraft Fire Barrier Simulator Testing.

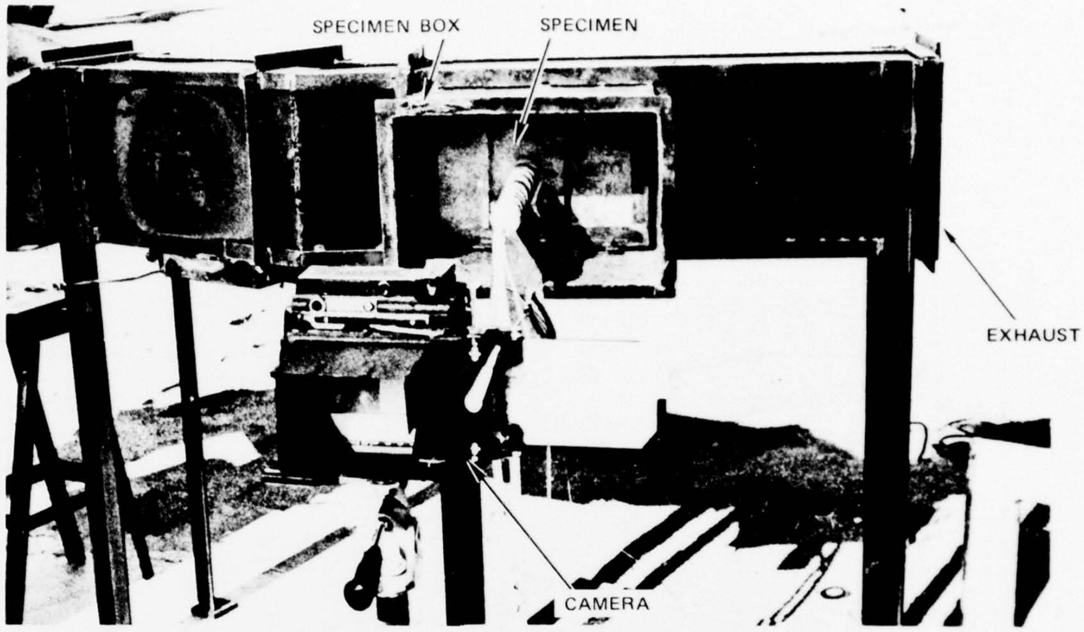


FIGURE 5. Aircraft Fire Simulator Test Setup.

Temperature of the ambient air was measured using a mercury-in-glass thermometer. In data assessment this value was then used as the reference temperature of the thermocouple. The millivolt reading obtained was then converted to degrees and this value added to the reference. The desired temperature accuracy for these tests was not extensive; thus, a high-accuracy reference system was not warranted.

MATERIALS TESTED

Both organic and inorganic materials were tested and evaluated. Organic materials investigated consisted of various formulations of polyurethane, closed cell, rigid foams. Inorganics tested were flexible silicon and alumina silica rigidized materials. Additionally, metallics combined with both organic and inorganic insulators were tested. A detailed listing of all materials and combinations of materials tested is presented in Table 1.

TABLE 1. Materials Evaluated in Aircraft Fire Simulator Tests.

Test specimen description				Source	Remarks
Designation	Thickness, cm (in.)	Density, kg/m^3 (lb/ft^3)	Characteristics		
Organic Materials					
5A43	5.1 (2)	40 (2.50)	Glass reinforced, semirigid (no outer skin)	NWC Mixed	Ingredients supplied by AVCO, mixed to NASA specifications
5A43	2.5, 5.1, 7.6 (1, 2, 3)	50 to 65 (3 to 4)	Spray molded (without skin) (also closed-mold type)	AVCO	...
BX352-P	7.6 (3)	50 to 60 (3 to 3.75)	Glass reinforced, semirigid	Grumman	Spray-molded
5F14RS	5.1 (2)	50 to 65 (3 to 4)	Silica fiber reinforced, semirigid	NASA-Ames	Molded
Inorganic Materials					
WRP-X-AQ	2.5 (1)	320 (dry) (20)	Ceramic felt	Grumman	Density up to 1120 kg/m^3 (wet)
...	5.1 (2)	320	Silicone foam, flexible	Grumman	...
Metallics					
301 CRES + TBS-758	0.64 (0.27)	...	Silicon ablative on stainless	Grumman	...
Fiber glass + TBS-758	0.68 (0.29)	...	Silicon ablative on fiber glass/epoxy	Grumman	Fiber glass on both sides of silicon
321 CRES + 5F14RF	2.5, 5.1 (1, 2)	...	Polyurethane foam on stainless	NASA-Ames	Fireside of foam covered with aluminum sheet
Intumescent Coating					
1000 & 1000 modified; 1010, 1200 (flexible sheet); 1600B; 313				AVCO	...
477 GF				Grumman	...
M-30; Lacquer type, semiflexible sheet				NASA-Ames	Lacquer type is P-nasa salt in nitrocellulose lacquer

Preliminary materials testing was performed at the NASA-Ames Research Center, under NWC cognizance, to develop a data base for the fire barrier system concept. The purpose of this test effort was to investigate thermal characteristics of various material formulations. These tests provided a means of determining physical variables within the formulations and detailed thermal data for each formulation. These data were subsequently used in the development of candidate barrier systems for aircraft fire simulator tests, and as a base for a NASA-prepared draft of a proposed aircraft fire barrier process and systems specification. Tests conducted at NASA-Ames Research Center are presented in Appendix A.

The proposed matrix of tests for organic materials included the following variables:

Specimen thickness .... 2.5, 5.0, and 7.6 cm (1, 2, and 3 in.)
Gap spacing .... 3.2, 6.4, and 9.5 mm (0.125, 0.250, and 0.375 inch)
Joint type .... lap and butt types
Coatings .... intumescent paints, nine different types

A construction technique originally proposed by Grumman Aerospace Corporation was to cast the foam in the desired shape. This gives the foam block a high-density, thin skin which is thought to strengthen the char against the abrasiveness of the air-driven flame.

TEST SPECIMEN PREPARATION

As-received specimen materials came in various sizes and thicknesses. The materials were cleaned to remove mold release materials used in preparation of the samples. Specimen samples were cut to fit the specimen holder, if needed, and candidate intumescent coating was applied and cured as required.

Three basic mounting techniques were employed for specimen testing. These were (1) use of continuous blocks to obtain the thermal resistance data, (2) use of three individual blocks butted together to determine the effect of butt joints, (3) use of individual intumescent-coated blocks sized so that, when installed in the mounting fixture, desired gaps could be established between the blocks. Gap spacing was accomplished using steel spacers of the desired thickness placed at the bottom and top sides of the blocks installed in the mounting fixture. The completed assembly was then mounted into a frame, positioned in the aircraft fire simulator and instrumentation sensors were attached as required.

TEST PROCEDURE

A given test specimen was mounted in the aircraft fire simulator and thermocouples were installed. Instrumentation calibration was conducted on the amplifier/recorder combination using a substitute voltage source. This was followed by photographic documentation of the pretest configuration.

Time was kept by the recorder, as its motion is by direct drive using a synchronous motor. The recorder rate error was less then 5 sec in 5 min, which was adequate for the accuracy desired.

To initiate a test, fuel was introduced into the fire pan and ignited. Airflow was initiated and the fuel flow rate was adjusted to give a full flame over the sample. Burner pan fuel flow was regulated to stabilize heat flux at 11.35 W/cm^2 (10 BTU/ft^2-sec) with thermal buildup according to the schedule shown in Figure 6. Recorder time zero was noted when flame first reached the test specimen. In tests with gapped specimens, intumescent initiation was aided by back-pressuring the tunnel exhaust or by lowering the pressure at the unexposed specimen face.

Tests were continued for 15 min or until specimen burnthrough, whichever occurred first. During one series of tests, specimen strength while exposed to fire was determined by conducting the standard burn test for 5 min, then initiating and gradually increasing the pressure differential across the specimen until failure occurred, if at all. During another series of tests, backside still-air temperature as functions of time and distance (measured normally from the specimen) were obtained from 5.1 to 34.3 cm (2 to 13.5 in.) from the sample.

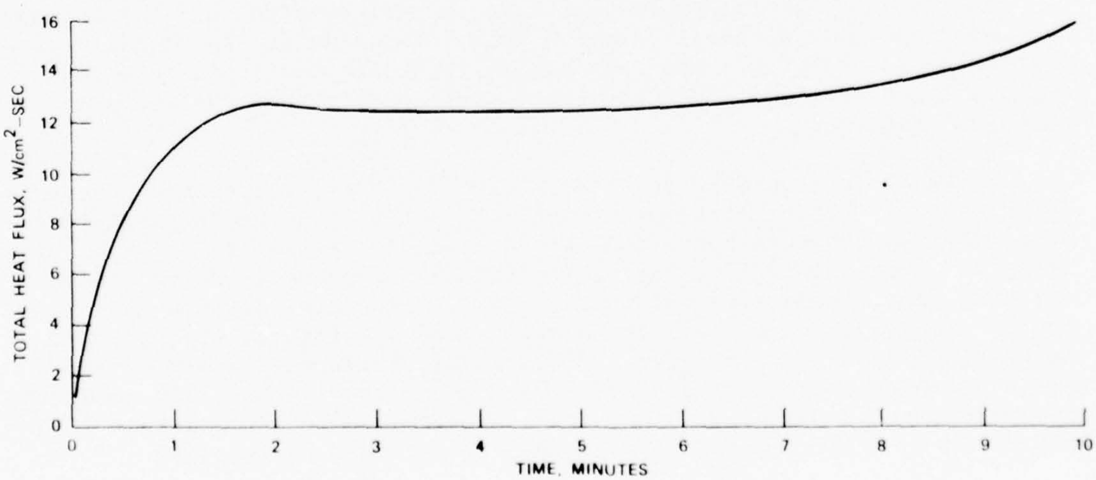


FIGURE 6. Typical Heat Flux Schedule for Aircraft Fire Simulator Tests.

TEST RESULTS

Results of all testing is summarized in Table 2. In the first series of tests, continuous specimens were evaluated to determine thermal toughness with no gaps or pressure differential loading applied. Normalizing the results to installed weight (g/cm^2) required for each minute of thermal protection showed that the 5F14RS material provides a given level of protection at the lightest weight for the materials tested. These data are shown in Table 3.

The second series of tests measured specimen strength while exposed to fire. Clearance gap intumescent seal strength evaluation was included to determine overall barrier system resistance to pressure loading. Intumescent chars of 477GF and 1600 materials failed at 3.55 and 7.62 cm-H_2O (1.4 and 3.0 in.-H_2O), respectively. The 5A43 and the 5F14RS foam chars failed at 15.24 and 19.05 cm-H_2O (6.0 and 7.5 in.-H_2O) pressure differential, respectively, without reaching the failure point for the 313 intumescent char. These data are presented in Table 4.

Resistance to burnthrough for gap-filling intumescent char under no-load conditions is shown in Figures 7 and 8. The M-30 material was not tested under these conditions; however, results of the load tests indicate that the M-30 material is comparable to the 1200 intumescent flexible sheet. Additionally, several combination intumescent coating schemes were investigated. The 1000 modified applied over the 1200 sheet burned through in 6.0 min at 5.1 cm (2 in.) foam thickness; 1000 over 1200 sheet burned through in 10.0 min at the same specimen thickness.

In later tests the operating procedures were modified to include forcing flame through foam block gaps to accelerate the gap sealing rate. Initiation of intumescent action was rapid, but as the gap closed, outgassing inhibited final closure rate.

One series of tests was devoted to investigating barrier penetrations. Aluminum tubing, stainless steel tubing, and electrical wire bundles passing through several of the barrier types were tested. Sealing agents used in these tests consisted of intumescent paints, silicons, ceramics, fireshield cloth, and wire cloth. Table 5 details the specimen configurations tested and presents the results. Melting of the penetrating medium was the predominant failure mode; where this did not occur, autoignition of the fireshield and wire cloth sealants occurred 45 sec into the test and the silicon sealant ignition at about 5 minutes.

TABLE 2. Summary of Experiments Conducted Against Nonmetallics in Aircraft Fire Simulator.

Specimen description					Face coating			Gap coating					Burn-through time, min	Comments
Type	Thickness		Density		Type	Thickness		Gap		Type	Thickness			
	cm	in.[a]	kg/m³	lb/ft³		mm	in.	mm	in.		mm	in.		
WPR Felt	2.54	1	400	24.98	None	...	...	None		...	None		20+	Continuous specimen
Silicon	5.08	2	320	19.98	None	...	...	None		...	...	...	14.0	Continuous specimen
5A43	7.62	3	77	4.8	1200	0.51	0.020	None		...	...	...	13.1	Continuous specimen
5A43	5.08	2	69	4.3	None	...	...	None		...	...	...	4.5	Edge failure
			67	4.2	313	0.25	0.010	None		...	...	...	13.2	Continuous specimen
5F14RS	5.08	2	71	4.4	None	...	...	None		...	...	...	6.7	Edge failure
			75	4.7	None	...	...	None		...	...	...	15+	No burnthrough
5A43	5.08	2	55	3.4	1200	0.51	0.020	9.5	0.37	M-30	5.59	0.22	5.0[b]	15.24cm-H_2O (6 in.-H_2O)
Silicon	5.08	2	320	19.98	None	...	...	Butt[c]		None	...	...	8.0	Failed joint, no load ΔP
BX352-P	7.62	3	60	3.75	1600	0.51	0.020	6.3	0.25	1600	1.5	0.06	5.0	7.62cm-H_2O (3 in.-H_2O)
BX352-P	7.62	3	60	3.75	477GF	0.51	0.020	6.3	0.25	477GF	1.5	0.06	5.0	3.55cm-H_2O (1.4 in.-H_2O)
5F14RS	5.08	2	60	3.75	1200	0.51	0.020	9.5	0.37	M-30	5.59	0.22	5.0	19.05cm-H_2O (7.5 in.-H_2O)
WPR Felt	2.54	1	400	24.98	None	...	...	Butt		Ceramcoat	...	...	10.0	12.7cm-H_2O (5 in.-H_2O)
	2.54	1	59	3.7									4.0	
5A43	2.54	1	62	3.9									4.75	Edge failure
	5.08	2	59	3.7	1000[d]	0.25	0.010	Butt		1000[d]	1.52	0.06	8.0	
	7.62	3	48	3.0									7.5	
	2.54	1	61	3.8									4.5	
5A43	5.08	2	52	3.3	1010	0.25	0.010	Butt		1010	1.52	0.06	5.75	
	7.62	3	55	3.4									8.5	
5A43 (2 ea)	2.54	1	63	3.9	313	0.25	0.010	Butt		313	1.52	0.06	3.0 2.5	
5A43 cut (2 ea)	5.08	2	40	2.5	Lacq	0.25	0.010	Butt		Lacq	1.02 2.03	0.04 0.08	3.5 4.0	Lacquer coating
	2.54	1	56	3.5									2.75	
5A43	5.00	2	63	3.93	1000	0.25	0.010	6.3	0.25	1000	1.52	0.06	2.9	
	7.62	3	51	3.18									3.5	
	7.62	3	54	3.37	1000								5.0	
5A43	5.08	2	52	3.35	1000[d]	0.25	0.010	6.35	0.25	1000[d]	1.52	0.06	6.0	Edge failure
	7.62	3	58	3.62	1000[d]								8.5	

See footnotes at end of table.

TABLE 2. (Contd.)

Specimen description					Face coating			Gap coating					Burn-through time, min	Comments
Type	Thickness		Density		Type	Thickness		Gap		Type	Thickness			
	cm	in.[a]	kg/m^3	lb/ft^3		mm	in.	mm	in.		mm	in.		
5A43	2.54 5.08 7.62	1 2 3	61 53 53	3.80 3.31 3.31	1010	0.25	0.010	6.35	0.25	1010	1.52	0.06	3.0 2.5 4.75	
5A43	5.08 7.62 5.08	2 3 2	53 49 73	3.31 3.06 4.56	313 313 1000	0.25	0.010	6.35	0.25	313 313 1200	1.52	0.06	5.0 8.5 4.8	Edge failure
5A43	5.08 2.54	2 1	50 57	3.2 3.56	1000 Lacq	0.25	0.010	6.35	0.25	12/10 Lacq	4.57 1.02	0.18 0.04	10.0 2.25	1000 over 1200 coating Lacquer coating
5A43	2.54 5.08 7.62	1 2 3	58 54 57	3.62 3.37 3.56	1000	0.25	0.010	9.53	0.375	1000	1.52	0.06	3.6 4.75 5.5	
5A43	5.08 7.62 7.62	2 3 3	62 48 71	3.87 3.00 4.43	1000[d]	0.25	0.010	9.53	0.375	1000[d]	1.52	0.06	3.75 6.5 11.75	
5A43	2.54 7.62	1 3	64 50	4.00 3.12	1010 1010	0.25	0.010	9.53	0.375	1010 1010	1.52	0.06	2.25 5.0	
5A43	5.08 7.62	2 3	59 53	3.68 3.31	313 313					313 313	1.52	0.06	3.25 7.25	Gap never closed completely
5A43	7.62 7.62	3 3	53 53	3.31 3.31	1600B 1600B	0.25	0.010	9.53	0.375	1600B 1600B	1.52	0.06	5.75 7.2	
5A43	2.54 5.08 5.08	1 2 2	... 86 57	... 5.37 3.36	1200 1000[d] 1010	0.25	0.010	9.53	0.375	1200 1000[d] 12/10	1.52 2.03 2.54	0.06 0.08 1.00	4.0 6.0 3.5	 1000 over 1200 coating
5A43	5.08 7.62 2.54	2 3 1	... ...	... ...	1200	0.25	0.010	9.53	0.375	1200	2.03	0.08	10.1 20+ 3.5	No burnthrough

[a] Metric equivalent in inches.
[b] Differential pressure applied, values represent load test Δ.
[c] Specimen blocks butted together without gap.
[d] 1000 modified.

TABLE 3. Aircraft Fire Simulator Data on Thermal Resistance of Candidate Materials Without Pressure Differential Loading.

Test specimen description					Face coating			Burn-through time, min	Material required per minute protection[a]	
Designation	Thickness		Density		Type	Thickness				
	cm	in.	kg/m^3	lb/ft^3		mm	in.		g/cm^2	lb/ft^2
5A43	5.08	2	69	4.30	None	...	...	4.5[b]	...	
5A43	7.62	3	77	4.80	1200	0.51	0.020	13.0	0.045	0.09
Silicon	5.08	2	320	19.98	None	...	...	14.0	0.125	0.26
WPR felt	2.54	1	400	24.97	None	...	...	20+	0.041	0.08
5F14RS	5.08	2	71	4.43	None	...	...	6.8[b]	...	
5F14RS	5.08	2	75	4.68	None	...	...	15+	0.026	0.05
5F14RS	5.08	2	67	4.18	313	0.25	0.010	13.3	0.026	0.05

[a] Installed unit area.
[b] Edge failure rather than actual burnthrough.

TABLE 4. Gap-Filling Intumescent Char Strength During Burn Test.

Specimen description			Cap coating			Maximum pressure[a] differential	
Designation	Thickness		Type	Thickness			
	cm	in.		mm	in.	kg/cm^2	lb/in^2
5A43	5.08	2	M-30	5.59	0.22	0.42	5.97
BX352-P	7.62	3	1600	1.50	0.06	0.21	2.98
BX352-P	7.62	3	477GF	1.50	0.06	0.60	1.42
5F14RS	5.08	2	M-30	5.59	0.22	0.53	7.53

[a] Load applied 5 minutes after burn initiation and gradually increased to failure.

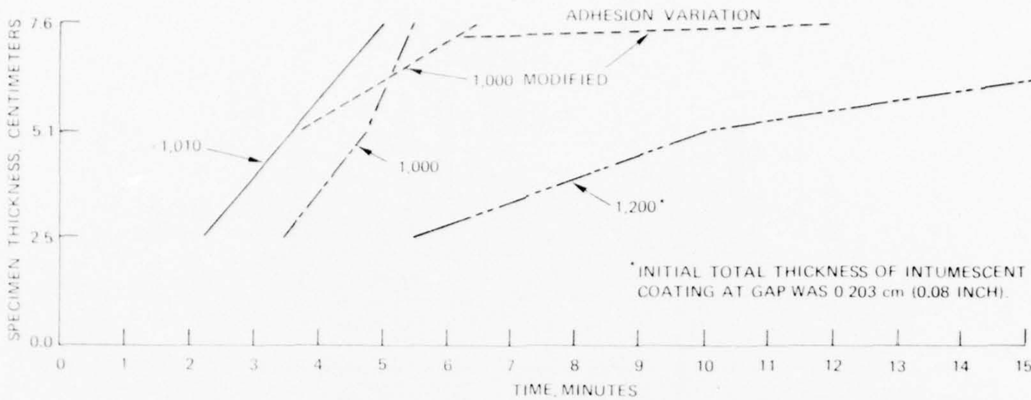


FIGURE 7. Burnthrough Time for Intumescent Materials (0.152 cm (0.06 inch) Thickness) Filling a 0.95-cm Gap in 5A43 Foam Specimen.

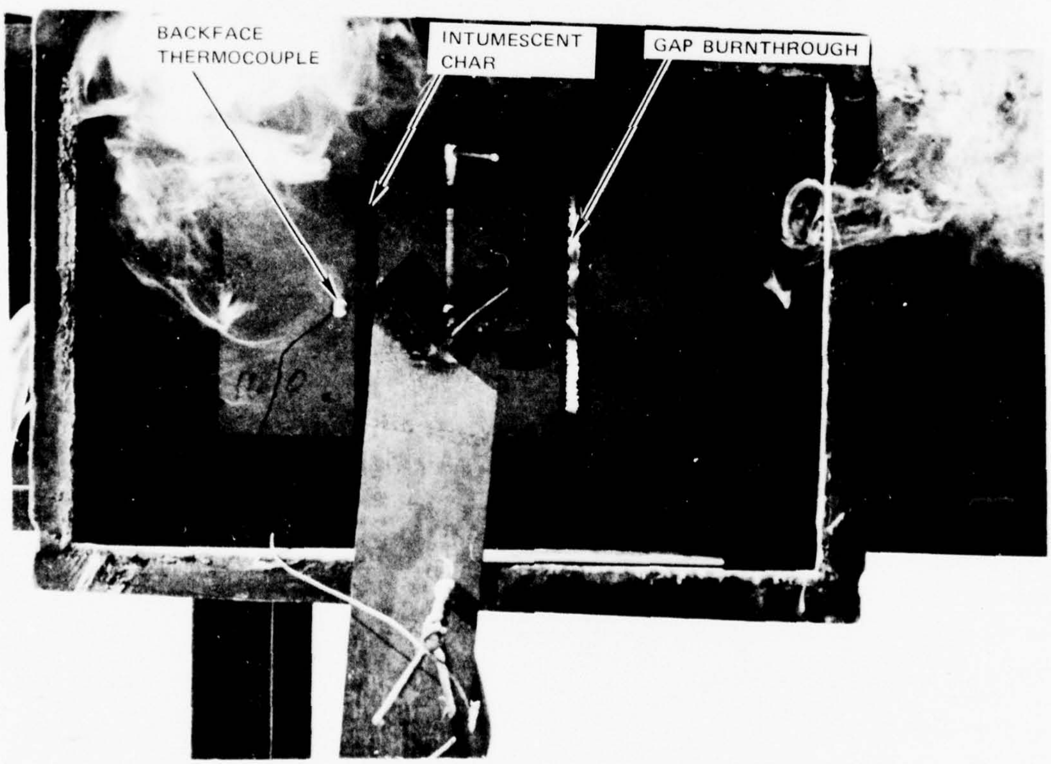


FIGURE 8. Candidate Specimen Showing Failure of Intumescent Coating at Specimen Gap.

TABLE 5. Summary of Experiments Conducted on Effects of Penetrating Structures on Fire Barrier.

Barrier description			Penetrating structure							Burn-through time, min	Comments
Material	Thickness		Type	Diameter		Coating	Thickness		Sealant		
	cm	in.		cm	in.		cm	in.			
301 CRES/ TBS-758	0.68	0.27	Tube, Al	5.1	2	477GF + ceramic	0.32	0.13	TBS-758	8.2	Intumescent coating
	0.68	0.27	Tube, Al	5.1	2	TBS-757	0.32	0.13	TBS-758	4.3	
	0.68	0.27	Tube, CRES	5.1	2	None	...	...	TBS-758	4.5[a]	
	0.68	0.27	Tube, double-walled	5.1	2	None	...	...	TBS-758	5.1[a]	Inner tube Al, outer CRES
5F14RS	5.1	2.0	Tube, Al	5.1	2	313	0.13	0.05	313	2.0	Intumescent coating
301 CRES/ TBS-758	0.68	0.27	Wire bundle	2.5	1	None	...	...	JM 88	0.6[a]	Fireshield sealant
	0.68	0.27	Wire bundle	2.5	1	None	...	...	GC110V3A	0.6[a]	Wire cloth sealant
	0.68	0.27	Wire bundle	2.5	1	None	...	...	TBS-758	5.4	
5F14RS	5.1	2.0	Wire bundle	2.5	1	313	0.25	0.10	313	7.0+[b]	Intumescent coating

[a] Backface of sealant ignited rather than burnthrough.
[b] Test terminated without burnthrough occurring.

Backside still-air temperature data as functions of time and distance for the TBS-758 silicon-coated stainless steel sheet are presented in Figure 9. The 205°C temperature requirement at 5 min (reduced time requirement) measured 15 cm from the backface was just met with this barrier configuration. Metal-backed silicon joints, butt and lapped, were tested. The butt joint failed at about 4 min into the burn test. The lap joint (5.1 cm overlap) failed after 4.7 min of fire exposure. One burn test was conducted with the silicon insulator faced on both sides with impregnated fiber glass. This test specimen included a lap joint. Rapid erosion of the fire-exposed fiber glass occurred with joint failure at 60 sec after start of the burn.

Samples of the 5F14RS organic foam were prepared at thicknesses of 2.54 cm (1 inch) and 5.1 cm (2 in.). The foam was edged with 0.25 cm of M-30 intumescent sheet material. The fire-exposed face of the foam was covered with 0.51-mm-thick 2024 aluminum and the backface was covered with 0.51-mm T321 stainless steel. The 2.54-cm-thick test specimen still-air temperature 15 cm (6 in.) from the backface exceeded 205°C (400°F) 4.5 min after start of burn test. The 5.1-cm-thick specimen did not exceed the 205°C temperature criterion during an entire 15-min test.

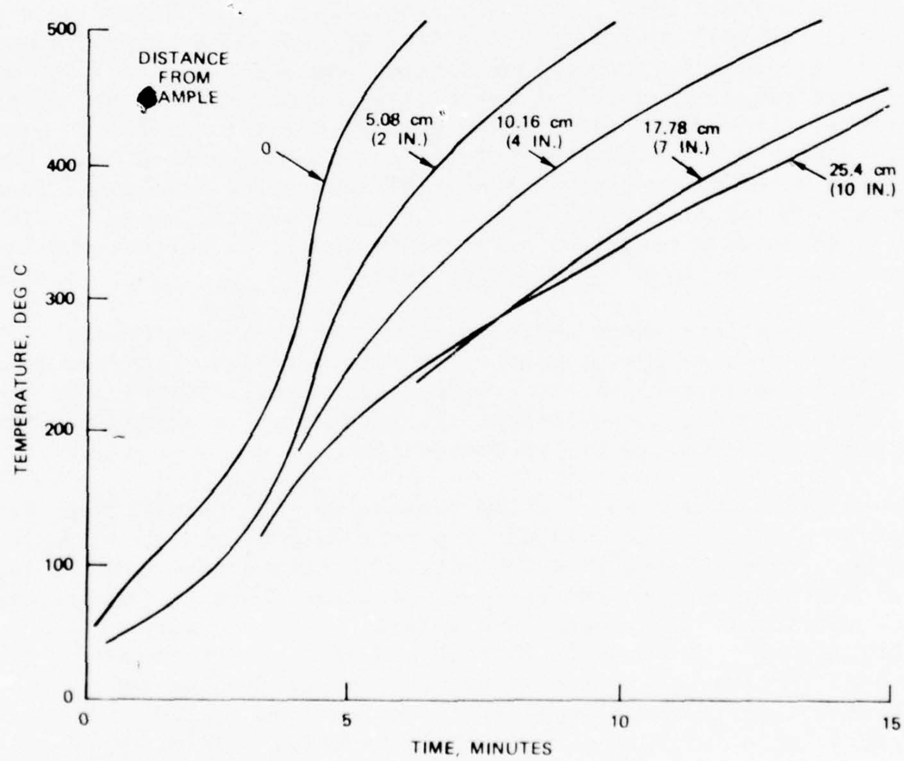


FIGURE 9. Backface Temperature Data for Stainless Steel Sheet Coated With TBS-758 Silicon.

TEST OBSERVATIONS

POLYURETHANE FOAMS

Foam specimen anomalies had a noticeable effect on test results. In casting relatively large blocks of fiber-reinforced polyurethane type foams, the mixed ingredients are injected into the bottom of a mold and then allowed to free-rise to the top. This process not only tends to orient the reinforcing fibers with the rise direction, but also creates homogeneity variations with foam density being greatest at the bottom of a casting block and gradually decreasing toward the top. Color variations in some of the specimens indicated that some of the isocyanate had not completely reacted. These process variations allowed for the presence of excessive voids in some of the samples, resulting in premature failures. No attempt was made to nondestructively measure foam homogeneity. The use of "soft" X-rays or acoustical techniques may provide this capability.

Of the polyurethane foam types investigated, the 5F14RS foam (basically the 5A43 formulation modified by reduced catalyst, substitution of silica fibers for glass fibers, and addition of a high-temperature reacting additive) was clearly superior in terms of thermal resistance. Indeed, it could often prevent burnthrough for in excess of 10 min with no supplemental intumescent coating protection. However, it must be noted that this was a special laboratory hand-mixed foam with no production experience behind it. Any of the other tested polyurethane foams could be made to resist burnthrough under the tested conditions with the aid of a proper intumescent coating.

In applications where a predominant flow direction exists for the fire-exposed side of polyurethane foam type barriers, the foam located most upstream will receive the greatest heat load. This occurs because foam smoke outgassing, when exposed to fire, travels downstream forming a thickening boundary layer for protection.

Even with intumescent coating protection, the polyurethane foams burn down to their basic carbonaceous char form within about 5 min after exposure to fires of the test intensity. Little actual test or measurement data of physical characteristics of these chars at temperature exist. Their ability to withstand internal aircraft airflow generated and vibrational type loads is unknown and must be determined prior to any actual incorporation into aircraft. In the limited tests conducted with pressure differential applied loads the foam failed at relatively low levels; this suggests that metallic backside reinforcement would probably be required to meet environmental criteria during an actual fire.

Sizing for aircraft installation and methods of mechanical fastening of the foams was not investigated in this effort, but either of these factors could seriously affect the practicality of a given installation design. However, bonding of the foams to thin metal sheets, with all mechanical fastening being accomplished through the sheets, would appear to simplify this problem area.

INTUMESCENT PAINTS

Intumescent paint performance was also influenced by quality control of the particular coating and in its application process. Intumescent characteristics found desirable for thermal barrier application included formation of a mechanically strong insulating char (but of not especially large volume) on the exposed foam surfaces with rapid initial rise followed by maximum paint adhesion in the gap-filling application. Improper adhesion was sometimes noted by detachment of portions of the coating upon initial application of heat. Residual traces of releasing agent on the virgin foam blocks, from the casting operation, prior to coating application was the suspected fault for this failure mechanism.

In the exposed foam surfaces application, 1000 modified (with good adhesion) and the 1200 flexible sheet were found to be clearly superior to the other coatings tested. The M-30 semiflexible sheet, though not tested for this application, has laboratory-proven performance indicating that it is at least equal to the 1200 type coating. The sheet format is desirable because thickness and bonding quality control are greatly simplified when compared to spray-applied coatings.

In the gap-filling application, M-30 followed by 1200 sheet were the most efficient. However, initial swelling action for both of these materials is relatively slow and the application of a thin outer coating of a fast-rising material, such as 1000 modified, is recommended.

Many of the intumescent materials suffer from an environmental "leaching out" effect which tends to stain adjacent structures. While this staining agent is noncorrosive and the performance of the material is not measurably affected by this process, it is undesirable and can be prevented by application of a thin outer coating (10 mil) of saran.

Intumescent paint 313 exhibited erratic performance. Prior laboratory testing indicated this was a high-efficiency material. While no effort was made to determine why this irregular performance occurred, it is suspected that insufficient mechanical mixing of the ingredients and the incomplete removal of releasing agent from the foam specimens combined to cause this anomaly.

INORGANIC MATERIALS

Limited testing was conducted with two inorganic materials, a flexible silicon foam and a rigidized ceramic felt (designated WPR-X-AQ). Although high in density when compared to polyurethane foams, both materials exhibited high thermal resistance. The silicon foam did suffer from significant distortion prior to burnthrough and continued to burn for a number of minutes after test shutdown. This vigorous self-combustion characteristic indicates that the silicon could act as a fire relight source aboard an aircraft. The ceramic felt (visual inspection suggests that it is a dense mat of silica fibers rigidized with a ceramic-type binder) proved to be almost totally inert in the thermal test environment. Steam generation during the first 5 min of fire exposure indicated that the felt had absorbed a significant amount of water. Later laboratory tests showed that, after oven drying, the ceramic felt density was 320 kg/m^3 (20 lb/ft^3) but could be increased to 1,120 kg/m^3 (70 lb/ft^3) by water immersion without changing dimensions.

These two inorganic materials represent but a sample of a family of such insulators currently available. As such, they are indicative of thermal resistance, but do not necessarily represent the most efficient nor optimum inorganic material to be used for this particular application.

BARRIER PENETRATIONS

In the test conducted to determine effects of aluminum tubing and electrical wire bundle penetration of a fire barrier, the weak link failure mode predominated. The thin-wall aluminum tube was protected with 1.27 mm (0.050 inch) of 313 intumescent paint where it protruded into the fire stream. Once fire penetrated a weak spot in the tube, flamed propagation from the inside rapidly melted out the rest of the tube, thus defeating all other thermal protection, with the tube acting as a conduit for breaching the fire barrier. This phenomenon did not occur with the wire bundle. Although it melted where it was directly exposed to the fire stream, flame failed to penetrate the barrier during the 7-min burn test.

The ceramic insulation material for aluminum tube protection proved to be the most effective, with burnthrough time extended to over 8 minutes. The silicon material was marginal in this application, but thicker coatings (about 0.5 cm) should prove adequate. Backside autoignition of the various sealant materials proved to be a problem when the penetrating medium resisted burnthrough. Although sustained combustion of the silicon sealant occurred as early as 4.5 min burn test duration, actual burnthrough of the barrier at the penetrations did not occur until about 8 min burn time.

RECOMMENDATIONS

In any fire barrier scheme, all elements of the barrier and adjacent equipment and structure must be considered in order to realize an effective system. Selection of actual materials for use in fire barriers is a complicated decision based on space and weight allowances, availability of materials, fabrication and quality control requirements, environmental considerations, installations, inspection, and removal procedures as well as thermal resistance capability.

This effort concentrated on a fire barrier system for application in one region of a specific aircraft. It was not the objective of this study to recommend any one of the materials, but merely to test them and report the results. While some of the materials were clearly superior to others on a weight basis, all could be made to meet the basic thermal protection criteria. Final decision for any aircraft application must be based on all of the above-mentioned factors plus additional large-scale testing.

This program has clearly revealed the need for more research into developing a family of lightweight, practical, rugged, and efficient fire barriers suitable for selective incorporation into existing and future aircraft.

Appendix A
LIGHTWEIGHT FIRE BARRIER MATERIALS DEVELOPMENT FOR AIRCRAFT

FIRE BARRIER MATERIALS TESTING

Fire barrier material optimization was pursued at the NASA-Ames Research Center, Chemical Research Project Office under cognizance of the Naval Weapons Center, China Lake, Calif. This work is herein described for information purposes and will be published in detail, separately by NASA. NASA previously developed polyurethane foam for aircraft ballistic protection application.

FORMULATIONS

Ten formulations were investigated in thermally optimizing polyurethane foam. Three potentially significant variables were addressed within these formulations, namely (1) basic foam density, (2) alternate high-temperature-resistant reinforcing fibers, and (3) potassium floroborate (KBF_4).

Density variation of the basic polyurethane foam (5A43), flight-qualified and used to reduce ballistic damage, was easily controlled with the amount of Freon blowing agent used. Silica fibers were chosen to compare with conventional glass fibers, because the silica has the advantages of good strength and stability at high temperatures. Effects of adding KBF_4 were investigated, because it has previously been found to be endothermic at hydrocarbon fuel flame temperatures with the boron reacting with the carbonaceous char to form a more thermally stable network and hydrogen fluoride (HF) acting to reduce the flammable species at the foam-char surface.

The exact foam formulations used are contained in Table A-1. The ingredients were mixed one at a time in the order given, except that the MEG 440 polyol and the Freon liquid were thoroughly mixed together prior to addition to the ingredients preceding them. The final chemical, 33 LV, the catalyst agent, was mixed diluted by an equal amount, by volume, of Freon. Immediately after addition of the catalyst and rapid mixing, the final product was poured into the bottom of a waxed (releasing agent) mold and allowed to free-rise to the top of the mold. Mold dimensions were: height 41 cm (16 in.), width 41 cm, thickness 5 cm (2 in.). The foam was then allowed to cure for 24 hours prior to removal from the mold.

TABLE A-1. Polyurethane Foam Fire Barrier Formulations Evaluated.

Components	1	2	3	4	5	6	7	8	9	10
	Formulation parts by dry weight.									
Mondur MR	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Saran 113	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5
KBF4	...	...	...	16.5	16.5	16.5	16.5	16.5	...	...
Fyrol 2	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
MEG 440	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0
Freon 11	35.0	30.0	40.0	80.0	80.0	80.0	100.0	75.0	75.0	75.0
"E" glass	25.0	25.0	25.0	25.0	...	...	...	...	...	...
Refrasil 1/8 inch	...	...	...	...	...	6.5	25.0	6.5	6.5	6.5
Refrasil 1/4 inch	...	...	...	...	25.0	18.5	...	18.5	18.5	18.5
DC 195	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
33 LV	8.0	8.0	8.0	3.5	3.5	3.5	3.5	3.5	3.5	3.5

THERMAL SCREENING TEST PROCEDURES

The test specimen foam blocks were cut to 30.5 cm (12 in.) square by 5 cm (2 in.) thick. The blocks were mounted in asbestos frames and the unexposed face instrumented with chromel-alumel thermocouples as shown in Figure A-1. A 43-cm (17-inch) cubic stainless steel box structure was used in the last four tests with the specimen mounted so it was exposed in one wall of the box fixture. Inside, mounted 15 cm (6 in.) normal from the unexposed specimen face was a still-air thermocouple. The five sides of the box specimen that were not exposed to the furnace were insulated with 2.54-cm(1-inch)-thick blanket type silica insulation material. The test setup is shown in Figure A-2.

The NASA T-3 fire test facility was used to provide 11.35 W/cm^2-sec (10-BTU/ft^2-sec) of total heat flux with a cold wall temperature of approximately 900°C. When the oven was stabilized at this heat flux rate, the instrumented specimen was exposed to the flame and the thermocouple recorder (Esterline-Angus D-2020) started. Each individual test was terminated when the backface temperature of the specimen exceeded 205°C (400°F).

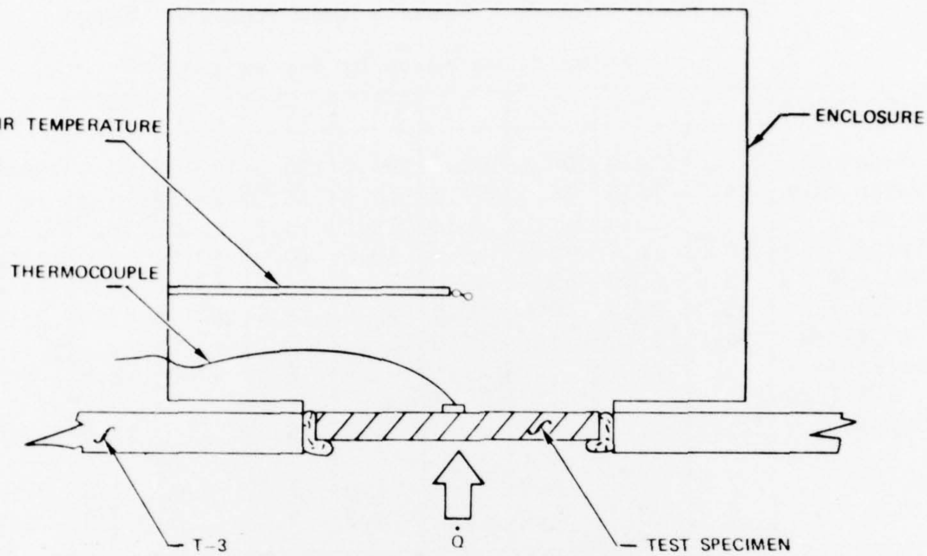


FIGURE A-1. Thermal Screening Test Setup.

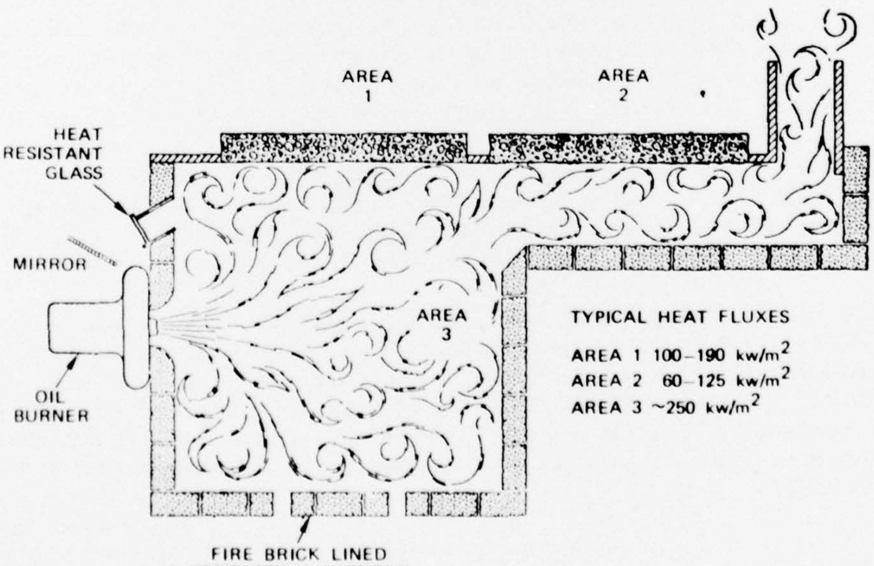


FIGURE A-2. NASA T-3 Fire Test Facility, Cross-Sectional View.

TEST RESULTS

THERMAL RESPONSE

First investigated was the effect of density on the thermal response of the basic 5A43 polyurethane foam. As can be seen from Figure A-3, a near-linear relationship exists when considering time to a given backface temperature as a function of density. The polyurethane foam acts as an efficient thermal ablator while decomposing to the basic char structure of fuzed glass fibers and carbon. This is then followed by a rapid rise to elevated temperatures at an approximately uniform and repeatable rate due to the char matrix thermal conductivity being about an order of magnitude greater than the virgin foam.

Next, the potential benefits of silica fibers as the reinforcing agent were determined. After the ablation process had been completed, the remaining silica char exhibited clearly superior thermal properties as compared to the glass char. Figure A-4 presents the results as time versus temperature data. The silica formed a white blanket-like surface to the fire, lowering the foam infrared absorptivity, thus reducing the effective heat transfer coefficient of the basic char structure.

The time versus temperature data for the polyurethane foam, with and without KBF_4 additive is presented in Figure A-5. Difference in initial ambient temperature alone can explain the apparent reduction in performance of the foam with the additive. The KBF_4 does not significantly enter into the reaction until it is at elevated temperatures (600°C). However, it appears to increase the apparent foam thermal conductivity until sufficient quantities of it are decomposing (in this test case when the backface temperature has reached about 150°C). At this point the foam apparent conductivity decreased to less than the basic silica and carbon char matrix.

Tests conducted with the unexposed face of the foam specimen enclosed in a box structure with the still-air temperature recorded are not representative of any actual aircraft structure thermal response to the barrier. Mass of the structure, coatings, distance from the barrier, view factors, air density, and air velocity must all be considered. However, it is an indication that air is an excellent insulator and criteria limiting the foam backface temperature to 200°C are extremely conservative. These data are contained in Table A-2. Table A-3 presents a summary of the results from each individual test. Details of the NASA T-3 fire test facility are shown in Figure A-6.

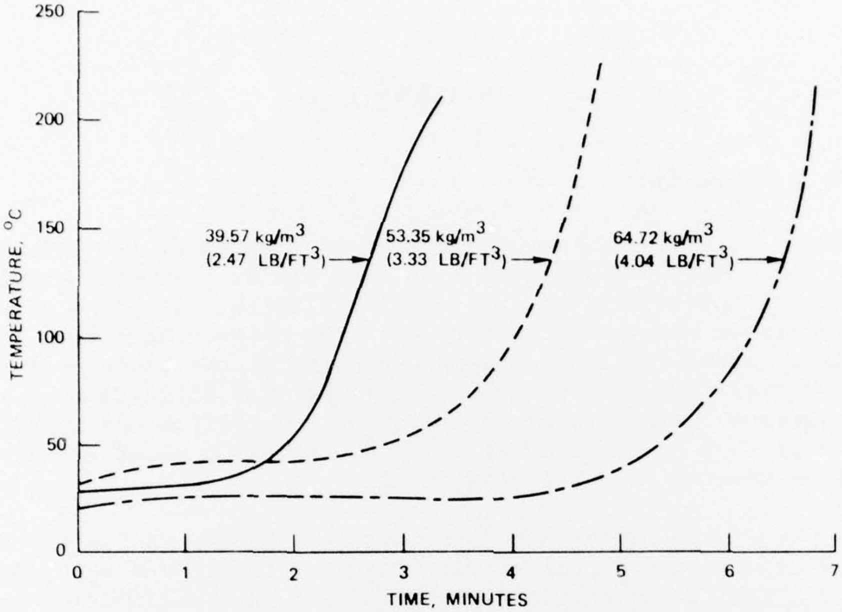


FIGURE A-3. NASA 5A43 Polyurethane Foam Thermal Response as a Function of Foam Density.

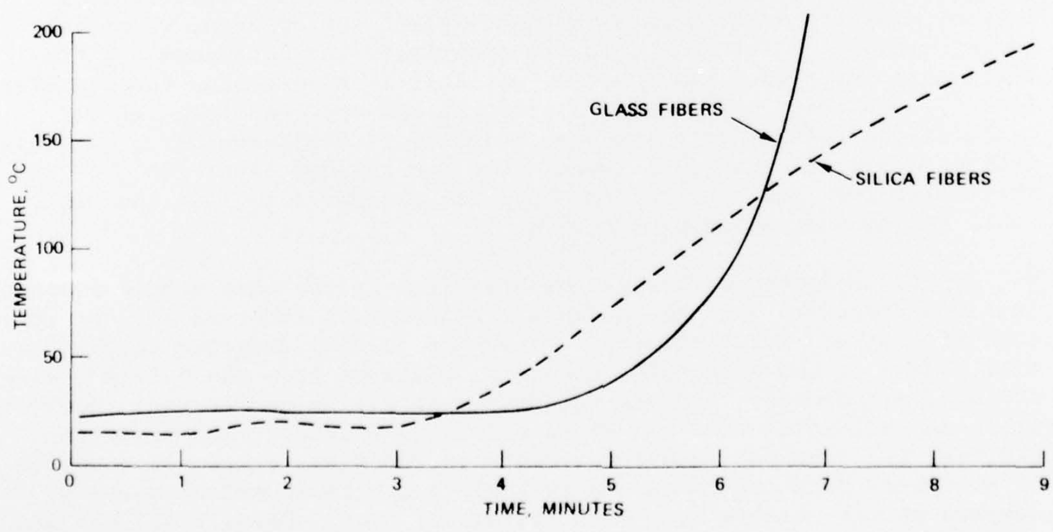


FIGURE A-4. NASA Polyurethane Foam Thermal Response as a Function of Reinforcing Fiber Type.

TABLE A-2. Time-to-Temperature Data for Polyurethane Foam Formulations.

Formulation No.	Time to 205°C (400°F),[a] min	Still-air temperature,[b] °C	Foam density	
			kg/m^3	lb/ft^3
1	4.75	...	53.35	3.33
2	6.50	...	64.72	4.04
3	3.17	...	39.57	2.47
4	6.00	...	65.20	4.07
5	3.50[c]	...	69.21	4.32
6	8.67	...	64.56	4.03
7	5.33	103	45.66	2.85
8	7.00	78	59.43	3.71
9	8.75	78	56.55	3.53
10	9.33	96	64.72	4.04

[a] Specimen backface.

[b] Thermocouple located 15 cm (6 in.) normal from backface of specimen. Temperature at 10 min burn duration.

[c] Excessive voids in specimen.

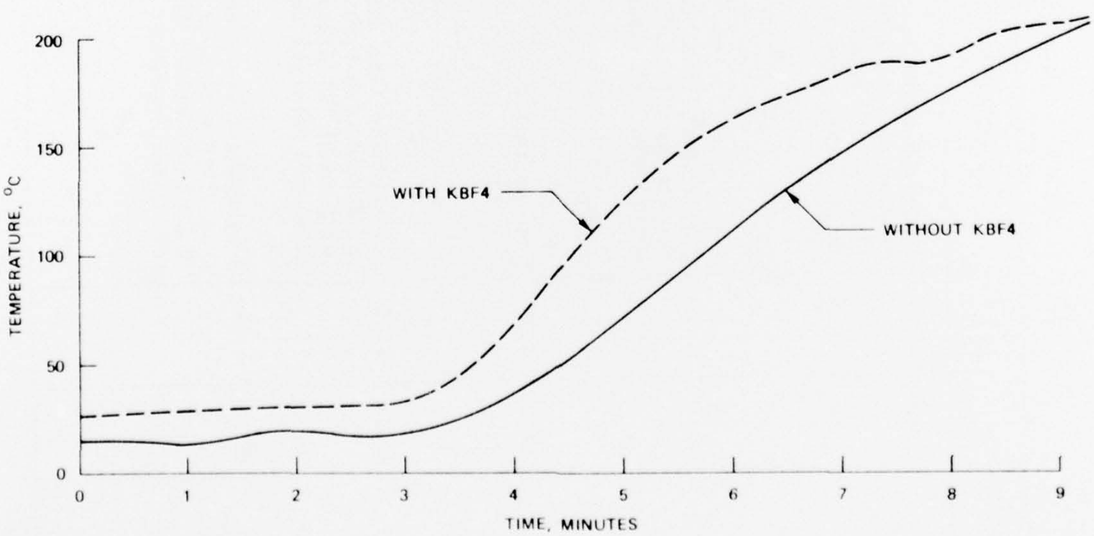


FIGURE A-5. NASA 5A43 Polyurethane Foam Thermal Response With and Without KBF4 Additive.

TABLE A-3. Summary of Thermal Tests of Polyurethane Foam Variations.

Test No.	Designation	Density, kg/m^3	Density, lb/ft^3	Description	Duration, min	Remarks
1	5A43	53.34	3.33	Polyurethane foam, cast reinforced with 2.54 cm (1 inch) "E" glass. Lap joint across center.	4.75	Initial heavy smoke generation. Specimen warpage observed at 2.0 min. Gap warpage initiated at 2.5 min. Gap thermocouple exceeded 540°C at 3.1 min. Escaping flame around corner seal at 3.5 min. Most of specimen reduced to char-like substance.
2	5A43	64.72	4.04	Polyurethane foam, cast reinforced with 1.90 cm (0.75 inch) "E" glass.	6.50	Initial heavy smoke generation. Warpage not as pronounced as during test 1. Some escaping flame around corner seal at 5.0 min, followed by steady rise of backface temperature.
3	5A43	39.56	2.47	Same as test 2.	3.17	Initial heavy smoke generation. Severe warpage with evidence of corner "hot spot" at 1.5 min. Backface temperature rise initiated at 5.0 min.
4	5F14	65.20	4.07	Polyurethane foam, cast reinforced with 1.90 cm (0.75 inch) "E" glass, KBF4 added and catalyst reduced.	6.00	Initial heavy smoke generation. Backface charring observed at 4.0 min. Significant backface temperature rise initiated at 5.0 min.
5	5F14RS	69.20	4.32	Polyurethane foam, cast reinforced with 0.63 cm (0.25 inch) silica fibers, KBF4 added, reduced catalyst.	3.50	Excessive voids noted in specimen prior to test. Noticeable backface temperature rise observed at 1.0 min. Noted formation of white "blanket" of silica on exposed face. Gas flow in oven caused local failures of this "blanket."

TABLE A-3. (Contd.)

Test No.	Designation	Density		Description	Duration, min	Remarks
		kg/m^3	lb/ft^3			
6	5F14RS	64.56	4.03	Polyurethane foam, cast reinforced with mixture of 0.63 and 0.32 cm (0.25 and 0.125 inch) silica fibers, KBF4 additive, reduced catalyst.	8.67	No backface temperature rise until 3.0 min. Minimum warpage. Excellent fire exposed face "blanket," resistant to oven wind forces. Slower temperature rise than previous specimens.
7	5F14RS	45.65	2.85	Polyurethane foam, cast reinforced with 0.32 cm (0.125 inch) silica fibers, KBF4 additive, reduced catalyst. Backface enclosed in box.	5.33	Initiation of backface temperature rise at 2.0 min. Good fire exposed face "blanket," but extremely weak with rapid erosion. At conclusion of test only a thin backface shell remained. Still-air temperature at 5.33 min was 56°C.
8	5F14RS	59.43	3.71	Same as test 6. Backface enclosed in box.	7.00	Initiation of backface temperature rise at 3.0 min. Strong, erosion-resistant "blanket" formation. Still-air temperature at 7.00 min was 52°C.
9	5F14RS	56.55	3.53	Polyurethane foam, cast reinforced with mixture of 0.63 and 0.32 cm (0.25 and 0.125 inch) silica fibers, no KBF4 additive, reduced catalyst. Backface enclosed in box.	8.75	Initiation of backface temperature rise at 4.0 min. Strong, erosion-resistant "blanket" formed. Still-air temperature at 8.75 min was 66°C. Post-test foam damage unrelated to test.
10	5F14RS	64.72	4.04	Same as test 9.	9.33	Initiation of backface temperature rise at 4.0 min. Strong, erosion-resistant "blanket" formed. Still-air temperature at 9.33 min was 85°C.

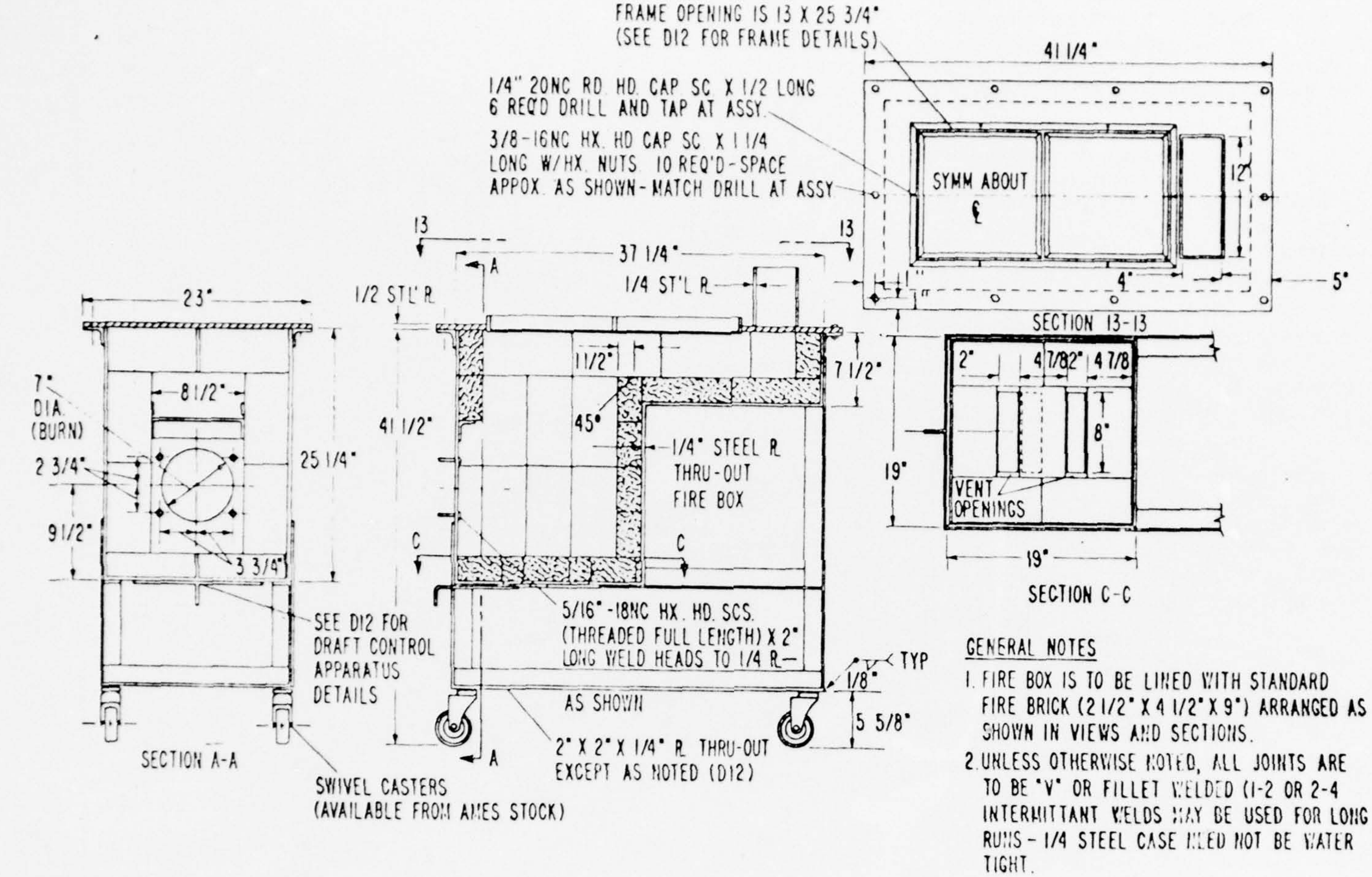


FIGURE A-6. Construction Detail, NASA T-3 Test Facility.

MECHANICAL PROPERTIES

All mechanical properties testing was conducted in accordance with the procedures and requirements of the American Society for Testing and Materials (ASTM). Table A-4 presents the results of these tests for the standard 5A43 polyurethane foam, for the 5A43 foam cast in molds (designated 5F14), and for the 5F14 foam with KBF_4 added and silica fibers substituted for glass fibers (designated 5F14RS).

The 5A43 foam is normally mixed and applied through a spray gun in multiple passes, thereby orienting the reinforcing fibers in a relatively random fashion. The 5F14 foam prepared for these tests was spray-gun applied into a confining mold, resulting in a more preferential orientation parallel to the rise direction. The 5F14RS foam was hand-mixed and poured into a confining mold with much the same resulting fiber orientation as the 5F14 foam. However, the silica fibers were only one-quarter as long as the glass fibers and had lower tensile strength. Molding of polyurethane foam creates a thin tough skin on all outer surfaces in direct contact with the mold. These skins were removed for the mechanical properties tests. Depending on geometry, the presence of these skins can more than double the mechanical strength of a foam block and friability is reduced to zero.

TABLE A-4. Physical Properties of Candidate Fire Barrier Polyurethane Foams.

Properties	ASTM	Units	Typical value		
			5A43	5F14	5F14RS
Density (apparent)		kg/m^3 (lb/ft^3)	39.72(2.48)	42.13(2.63)	41.65(2.60)
Comp. strength I, 10%[a]	D-1621	kg/cm^2 (psi)	1.97(28)	1.05(15)	0.49(7)
Modulus I	D-1621	kg/cm^2 (psi)	63.29(900)	21.10(300)	10.55(150)
Comp. strength II, 10%[b]	D-1621	kg/cm^2 (psi)	2.04(29)	2.18(31)	1.20(17)
Modulus II	D-1621	kg/cm^2 (psi)	70.32(1000)	80.87(31)	59.77(850)
Tensile strength I	D-1623	kg/cm^2 (psi)	2.53(36)	3.09(44)	1.48(21)
Tensile strength II	D-1623	kg/cm^2 (psi)	1.69(24)	1.48(21)	0.56(8)
Limiting oxygen index	...	percent	19.75	22.5	23.25
Friability (wt. loss at 10 min) Oak Block	...	percent	2	2	16

[a] Test loading applied perpendicular to rise direction of foam.
[b] Test loading applied parallel to rise direction of foam.

THERMAL SCREENING TEST CONCLUSIONS

When the class of polyurethane foams described herein are initially exposed to a fire they resist heat transfer by a combination of low thermal conductivity, transpirational cooling, sensible heating of outgassing by-products, boundary layer convection blockage, and carbon particle outgassing which scatters optical radiation. During this process the reinforcing fiber matrix serves to maintain the structural integrity of the charring barrier. Selection of reinforcing matrix material also determines the foam resistance to warpage and its mechanical strength while exposed to the fire. After depletion of the volatiles, heat flow through the barrier is dependent upon the conductive heat transfer coefficient of the remaining char structure, about 10 times that of the virgin foam.

Heating of the air space beyond the barrier unexposed face occurs through a combination of convective and radiative heat transfer. Radiation, being a function of temperature to the fourth power, rapidly becomes the primary mode of heat transfer providing burnthrough does not occur. Emissivity and view factors both regulate radiation heating rates. However, the still-air temperature data indicate that 205°C (400°F) measured 15 cm (6 in.) from the barrier materials will not be exceeded during the 10-min test for any of the formulations evaluated.

Conclusions about the foams tested are as follows:

1. Thermal insulation capability increases directly with increasing density.

2. Silica fiber reinforcement reduces foam warpage during heating by at least 50% when compared to glass fibers.

3. After depletion of volatiles, glass-reinforced foam allows a backface temperature rise of approximately 100°C (212°F) per minute while the silica fibers allow a rise rate of about 30°C (86°F) per minute.

4. Addition of potassium floroborate increases the silica fiber backface temperature rise rate to approximately 60°C (140°F) per minute until 150°C (300°F) then the rise rate decreases to 20°C (68°F) per minute.

5. The potassium floroborate additive increases the limiting oxygen index from 22.5 to 23.25%, thus increasing the foam resistance to combustion and flame spread.

6. Substitution of silica fibers in the lengths tested and addition of potassium floroborate reduces the polyurethane foam mechanical strength by about 50%.

Either of the two basic foam formulations will meet the thermal acceptance criteria. Except for mechanical strength, the 5F14RS formulation is clearly superior to the 5F14 formulation. Mechanical strength requirements have not been determined; therefore, the 5F14RS foam is recommended for additional testing and evaluation.

INITIAL DISTRIBUTION

16 Naval Air Systems Command
  AIR-03PAF, CDR Gibson (1)
  AIR-320B, Dr. Somoroff (1)
  AIR-5102B, CDR G. White (3)
  AIR-5102F, CAPT E. Lund (1)
  AIR-52032E, P. Weinberg (1)
  AIR-5204
    D. Atkinson (1)
    CAPT W. Rivers (1)
  AIR-530313, L. Budd (3)
  AIR-954 (2)
  PMA-241, E. Ingalls (1)
  PMA-265-2, CDR C. Cromer (1)
2 Naval Air Development Center, Johnsville
  Code 30C, R. Ritter (1)
  Code 30222, D. Pulley (1)
1 Naval Air Propulsion Test Center, Trenton (R. Vizzini)
1 Naval Ship Engineering Center, Hyattsville (SEC-6101E01, A. Winer)
2 Naval Ship Research and Development Center, Annapolis
  Code 2707, H. Schab (1)
  Code 2851, R. Foernsler (1)
2 Army Armament Command, Rock Island
  DRSAR-PPV, D. Kotecki (1)
  DRSAR-RDG, L. Artioli (1)
1 Army Aviation Systems Command, St. Louis (DRCPM-ASE, Col J. Keaton)
1 Army Air Mobility Research and Development Laboratories, Fort Eustis (SAVDL-EU-MOS, C. Pedriani)
1 Army Ballistics Research Laboratories, Aberdeen Proving Ground (DRXBR-VL, R. Bernier)
4 Watertown Arsenal, Materials and Mechanics Research Center, Watertown
  DRXMR-TM, Dr. E. Lenoe (1)
  DRXMR-R, Dr. G. Thomas (1)
  DRXMR-XC, Dr. E. Wright (1)
  DRXMR-K, S. Arnold (1)
1 Aeronautical Systems Division, Wright-Patterson Air Force Base (J. Cinelli, ASD/ENFEF)
1 Air Force Aero-Propulsion Laboratory, Wright-Patterson Air Force Base (SFH)
1 Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base (FES)
1 Directorate of Missile Safety, Norton Air Force Base (AFISC/SEFE, G. Economy)